






# First record of non-native *Xiphophorus maculatus* (Günther, 1866) (Cyprinodontiformes, Poeciliidae) in the state of Maranhão, northeastern Brazil

Felipe Polivanov Ottoni<sup>1</sup>, Erick Cristofore Guimarães<sup>2,3,4</sup>, Jadson Pinheiro Santos<sup>3</sup>, Pâmella Silva de Brito<sup>2,4</sup>, Josie South<sup>5</sup>, Pedro Henrique Negreiros de Bragança<sup>6\*</sup>

- 1 Laboratório de Sistemática e Ecologia de Organismos Aquáticos, Centro de Ciências Agrárias e Ambientais, Universidade Federal do Maranhão, Chapadinha, MA, Brazil • FPO: [fpotoni@gmail.com](mailto:fpotoni@gmail.com)  <https://orcid.org/0000-0002-9390-0918>
- 2 Programa de Pós-graduação Sociedade Natureza e Desenvolvimento, Instituto de Ciências da Educação, Universidade Federal do Oeste do Pará, Santarém, PA, Brazil • ECG: [erick.ictio@yahoo.com.br](mailto:erick.ictio@yahoo.com.br) <https://orcid.org/0000-0003-4480-5452>
- 3 Laboratório de Ictiofauna e Piscicultura Integrada, Centro de Ciências Agrárias, Campus Paulo VI, Universidade Estadual do Maranhão, São Luís, MA, Brazil JPS: [jadsonsantos@professor.uema.br](mailto:jadsonsantos@professor.uema.br)  <https://orcid.org/0000-0002-7521-8835>
- 4 Departamento de Biologia, Laboratório de Genética e Biologia Molecular, Universidade Federal do Maranhão, São Luís, MA, Brazil • PSB: [pamellabrito@hotmail.com.br](mailto:pamellabrito@hotmail.com.br)  <https://orcid.org/0000-0003-3945-4512>
- 5 School of Biology, Faculty of Biological Sciences, University of Leeds, Leeds, UK • JS: [josiesouth93@gmail.com](mailto:josiesouth93@gmail.com)  <https://orcid.org/0000-0002-6339-4225>
- 6 South African Institute for Aquatic Biodiversity, Makhanda, South Africa • PHNB: [pedrobra88@gmail.com](mailto:pedrobra88@gmail.com)  [p.braganca@saiab.ac.za](mailto:p.braganca@saiab.ac.za) <https://orcid.org/0000-0002-8357-7010>

\* Corresponding author

## Abstract

During a field expedition in 2020, we recorded specimens of an invasive platy fish, *Xiphophorus maculatus*, in the state of Maranhão, Brazil. This new occurrence, in the Municipality of São Luís, is only the second time that this non-native species has been found in northeastern Brazil. We provide an updated list of all invasive species recorded from the island of São Luís, highlighting the negative impacts they may confer for the native biodiversity.

## Keywords

Cyprinodontoidei, freshwater, geographic distribution, invasive species, Neotropical region, poeciliids, South America

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## Introduction

Poeciliidae *sensu* Bragança et al. (2018), popularly known as livebearers, comprises 275 valid species of fish (Fricke et al. 2021a). These occur in the Americas mainly in both fresh- and brackish-water environments, but they also being reported from saltwater and even hypersaline

environments (Trexler 1989), with the highest species diversity in Central America (Rosen and Bailey 1963; Lucinda 2005; Reznick et al. 2017). Species belonging to this family are easily recognized by the presence a copulatory organ in males, the gonopodium, consisting

of a modification of the anal-fin rays 3, 4, and 5 (Regan 1913; Rosen and Gordon 1953), as well as the presence of viviparity (matrotrophy) or ovoviviparity (lecithotrophy) (Rosen and Bailey 1963). Poeciliids include well-studied species such as guppies, *Poecilia reticulata* Peters, 1859, which are commonly used as experimental or model organisms in various areas of science, such as embryology, behaviour, ecology, and evolution. Moreover, they are very popular among aquarium hobbyists due to their bright colors, generalist life history traits, and ease of breeding in captivity (Lucinda 2005).

The poeciliid genus *Xiphophorus* Heckel, 1848 comprises 26 valid species (Fricke et al. 2021) and has a native distribution in Central America. According to Rosen (1979), *Xiphophorus* is readily distinguished from the other poeciliid genera by the possession of a unique microanatomy of the gonopodium tip (Rosen 1979: fig. 29). The distal portion of the gonopodium ray 3 possesses a large decurved hook followed by a series of simple segments and a series of elongate, ventrally directed and converging spines. The blade is a large, laterally compressed, calcified mass of granular tissue arising from the dorsal margin of the ray 3 terminal hook; the distal ramus of ray 4a curves downwards, conforming to the shape of the blade; there are two series of serrae separated by undifferentiated segments distally on ray 4p; ray 5a bends down towards ray 4p contacting the undifferentiated segments of ray 4p just proximal to the distal-most serrae of that ray; and rays 6 and 7 are swollen and clublike distally. In addition, the pelvic fins of species of this genus are modified, possessing an enlarged tip in the first ray, and with the second and third rays elongated (Rosen 1979). During mating, males swing their

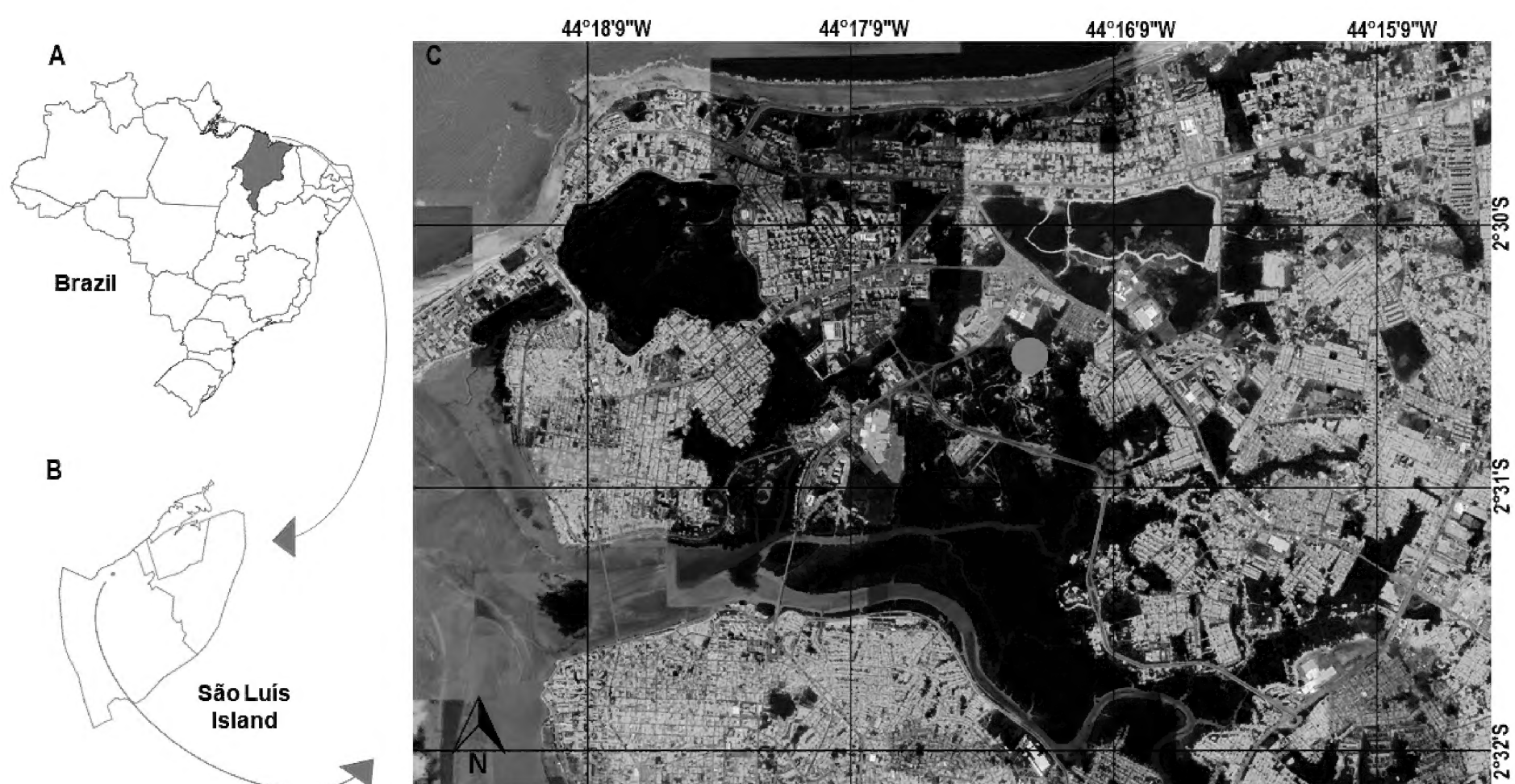
gonopodium forward, placing it against the erected pelvic (Clark and Kamrin 1951; Clark et al. 1954; Rosen and Tucker 1961).

*Xiphophorus maculatus* (Günther, 1866), popularly known as platy fish, was originally distributed in freshwater environments along the Atlantic slope of Mexico, Belize, and Guatemala (see Results for more details); however, it is now widely introduced to several countries, including Brazil (Lucinda 2003; Fricke et al. 2021b). The aquarium trade is the primary pathway for introduction of this species, as platy fishes are a common in the aquarium hobby as they present a plastic coloration, a wide tolerance to a variety of environmental parameters, and the distinctiveness of being a live-bearing fish (Kallman 1975; Nico and Fuller 2009; Ramos et al. 2020). However, despite being a widely distributed invasive species, the first record of *X. maculatus* for a river system of northeastern Brazil was only published in 2020, from the Municipality of João Pessoa, state of Paraíba (Ramos et al. 2020).

During a recent field expedition, we recorded for the first time *Xiphophorus maculatus* from the state of Maranhão, specifically in the Municipality of São Luís (Fig. 1). This new occurrence is only the second record of this introduced species from northeastern Brazil.

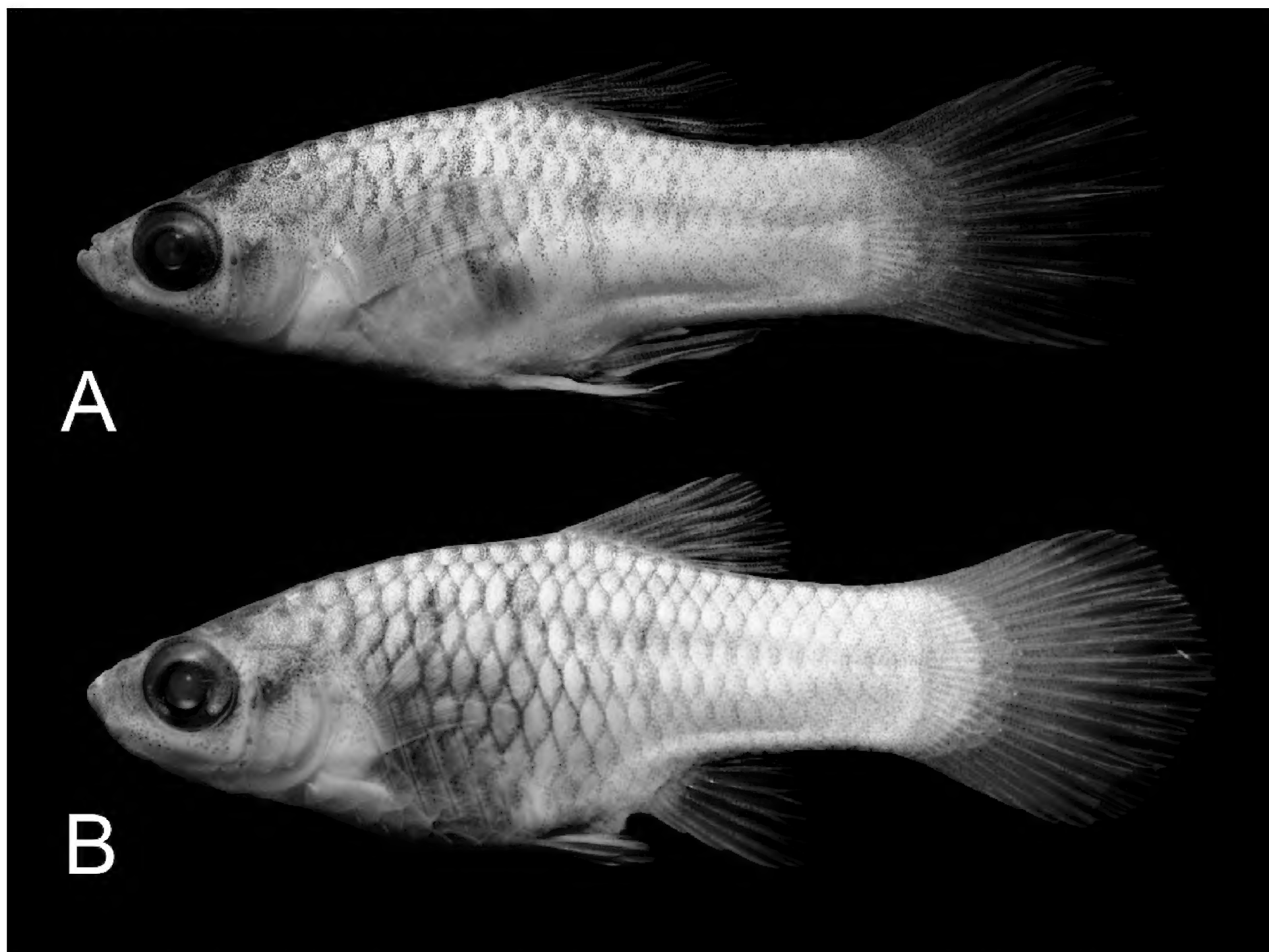
## Methods

**Sampling methods.** The collection was carried out during the daylight, using a seine net (2 m long  $\times$  1.8 m high; 2 mm mesh size). Specimens collected for this study were euthanized in a buffered solution of ethyl-3-amino-benzoate-methanesulfonate (MS-222) with a concentration



**Figure 1.** New record of the non-native *Xiphophorus maculatus* in the Anil river basin, Municipality of São Luís, Maranhão, northeastern Brazil. **A.** Brazil, state of Maranhão in grey. **B.** São Luís Island. **C.** Collecting site of the new record (represented by a red dot), satellite image adapted from Google Earth Pro v. 7.3.4.





**Figure 2.** *Xiphophorus maculatus*. **A.** Male, 19.9 mm SL (CICCAA 02682). **B.** Female, 18.0 mm SL mm SL (CICCAA 02682).

of 250 mg/l until the complete cease of opercular movements. The specimens were later fixed in formalin 10% for 10 days, after which they were preserved in 70% ethanol for long term storage. All the specimens were deposited at the Centro de Ciências Agrárias e Ambientais da Universidade Federal do Maranhão (CICCAA) ichthyological collection. All specimens were sampled under the permit 57414-3 from SISBIO (Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais).

**Identification.** The identification to species used diagnostic features provided by Rosen (1960), longitudinal series of scales, transversal scales, and fin counts following Bragança et al. (2020a), and nomenclature for gonopodial structures following Rosen and Gordon (1953). The standard length (SL) was measured with digital calipers from the upper jaw (premaxilla) to the posterior margin of the hypural plate.

## Results

Family Poeciliidae

*Xiphophorus maculatus* (Günther, 1866)

Figure 2

**Material examined.** BRAZIL – Maranhão • São Luís, Anil river basin, Igarapé Vinhais; 02°30'20.38"S, 044°

16'30.55"W; 25.III. 2020; E. Guimarães, J. Santos and P. Brito leg.; 1 ♂, 17.0 mm SL; 1 ♀, 17.9 mm SL, CICCAA 02683 • São Luís, Anil river basin, Igarapé Vinhais; 02°30'20.38"S, 044°16'30.55"W; 25.III. 2020; E. Guimarães, J. Santos and P. Brito leg.; 4 ♂ 16.4–20.4 mm SL; 3 ♀ 17.43–20.3 mm SL, CICCAA 02682.

On 25 March 2021 the water temperature at the site was 26.6 °C, dissolved oxygen was 5.17 mg/l, and the water depth was approximately 70 cm.

**Identification.** The specimens were identified as *X. maculatus* based on the presence of the following diagnostic characters as defined by Rosen (1960): lower caudal fin rays not elongated in adult males; absence of midlateral stripe; absence of a deep-lying ridge of black pigment midventrally on caudal peduncle; dorsal and anal fins rounded; dorsal fin not sexually dimorphic, usually with a faint or moderate diffuse dusk band near base. Gonopodium without claw at tip of ray 5a, rarely with a minute scythe-shaped or crescent element; distal serrae on ray 4p well developed and erect, seldom retrorse, 4 to 7 in number; ramus of ray 4a curved downward over blade, not hooked, and extending to tip of ray 4p; hook of ray 3 long and slender. The gonopodium tip of *X. maculatus* were illustrated by Rosen (1960: fig. 3B, C, 1979: fig. 29F) and Albornoz-Gárzon and Villa-Navarro (2017: fig. 4). Vertebrae usually number 27, or rarely 26. Scales in

lateral series are 22–25 and usually 23 or 24. Dorsal fin rays 7–10, usually 9 or 10.

**Geographic distribution and first record from Maranhão.** *Xiphophorus maculatus* originates from freshwater environments along the Atlantic slope of North and Central America in Mexico, Belize, and Guatemala, from Ciudad Veracruz, in Mexico to northern Belize (Lucinda 2003; Fricke et al. 2021b). However, the species have been introduced in several countries, including Brazil (Lucinda 2003; Fricke et al. 2021b). Here, we report the first record of this invasive species in Maranhão, in Igarapé Vinhais (Anil river basin), Municipality of São Luís (Figs. 1, 3). This is only the second record from northeastern Brazil (Ramos et al. 2020).

## Discussion

The phylogenetic relationships between *Xiphophorus* species has undergone a major shift with the inclusion of molecular data. Previously, four clades were identified on the basis of color patterns and morphological traits: the

northern and southern platys, representing two ancient lineages within *Xiphophorus*, and the northern and southern swordtails, forming a monophyletic group (Rosen 1979; Basolo 1991). This hypothesis suggested that the male elongated fin rays forming a sword-like structure, appeared only once in the evolution of the genus, in the common ancestor shared between the northern and southern swordtails. The more recent molecular phylogenies by Kang et al. (2013) and Jones et al. (2013), on the other hand, indicate an ancient single origin of the swordtail in the common ancestor of all *Xiphophorus*, with a subsequent loss along with the evolution of platys. These molecular studies recovered three major clades of *Xiphophorus*, the southern swordtails, the northern swordtails, and the platy fish, in which the northern platy fish forms a clade and the southern platies are not monophyletic within the platy fish clade. The southern swordtails were recovered as the most ancient lineage in the genus.

Two species of platies, *Xiphophorus variatus* (Meek, 1904) and *X. maculatus*, are widely utilized in the aquarium trade, with both being reported as invasive species.



**Figure 3.** Collecting site of the new record of *Xiphophorus maculatus*. Igarapé Vinhais (Anil river basin) at Sítio Santa Eulália, Municipality of São Luís, Maranhão, Brazil (02°30'20.38"S, 044°16'30.55"W).



Despite the lack of the sword structure in these two species, they can be easily distinguished by their color pattern and a series of morphological characters (Rosen 1960). *Xiphophorus variatus* differs from *X. maculatus* by the presence of two or more black zigzag mid-lateral stripes running from the base of caudal peduncle to the opercular membrane, by the presence of two or more oblique black lines extending downward from the midlateral stripes just behind pectoral base, and in having a sexually dimorphic dorsal fin which is higher and more smoothly rounded in adult males than in females. Despite their overlap, other useful characters distinguishing *X. variatus* from *X. maculatus* are the presence of 28 or 29 vertebrae, rarely 27 or 30 in *X. variatus* (vs. 27, rarely 26 in *X. maculatus*); 24–28 scales, usually 26, in the lateral line in *X. variatus* (vs. 22–25, usually 23 or 24 in *X. maculatus*); and 9–14 rays in the dorsal-fin, in *X. variatus* (vs. 7–10, usually 9 or 10 in *X. maculatus*). Phylogenetically, within the platies clade, both species are not closely related, with *X. maculatus* being recovered as a more ancient lineage (Kang et al. 2013) or even as sister to all other platy species (Jones et al. 2013), whereas *X. variatus* is recovered as a more derived lineage, sister to the northern platies clade (Jones et al. 2013; Kang et al. 2013).

Despite three decades of field campaigns in the state of Maranhão which surveyed the state's ichthyofauna, *X. maculatus* had not been detected in any previous collections (e.g., Garavello et al. 1998; Piorski 1998; Castro et al. 2002; Piorski et al. 2003; Pinheiro Júnior et al. 2005; Soares 2005; Castro et al. 2010; Barros et al. 2011; Martins and Oliveira 2011; Sousa et al. 2011; Fraga et al. 2012; Ramos et al. 2014; Ribeiro et al. 2014; Matavelli et al. 2015; Melo et al. 2016; Piorski et al. 2017; Abreu et al. 2019, 2020; Brito et al. 2019, 2020; Lima et al. 2019; Teixeira et al. 2019; Guimarães et al. 2020a, 2020b, 2021; Oliveira et al. 2020). However, from the island of São Luís, state of Maranhão, other non-native fishes have been recorded in various aquatic environments (freshwater, brackish, and marine habitats near the coast), including *Butis koilomatodon* (Bleeker, 1849) (Eleotridae), *Omobranchus punctatus* (Valenciennes, 1836) (Bleniidae), *Poecilia mexicana* Steindachner, 1863 (Poeciliidae), and *Poecilia reticulata* (Poeciliidae) (Lasso-Alcalá et al. 2011; Guimarães et al. 2017; Nogueira and Luvizotto-Santos 2018; Bragança et al. 2019, 2020b; Aguiar et al. 2021). A variety of pathways are likely responsible for these introductions, given the small body sizes of these species (Grabowska and Przybylski 2015). *Xiphophorus maculatus*, as well as other poeciliids, due to viviparity, can successfully establish invasive populations starting from one pregnant female (Grapputo et al. 2006; Deacon et al. 2011). Previous habitat invasions by these species due to the aquarium trade, ballast water discharges and stowaways, and mosquito larvae biological control have been suggested (Soares et al. 2012; Magalhães and Jacobi 2013, 2017; Bueno et al. 2021). Our new record of *X. maculatus* is the third invasive poeciliid species occurring in

natural environments of the island of São Luís (Nogueira and Luvizotto-Santos 2018; Bragança et al. 2019, 2020b).

Many poeciliid fishes are widespread and phenotypically plastic r-selected species that proliferate rapidly. Their successful establishment in new habitats are often facilitated by the degradation of natural habitats and urbanization of water bodies (Santana et al. 2020). Poeciliids have a perceived positive socio-economic value, with respect to economic potential and mosquito-borne disease control, despite no satisfactory studies indicating a dietary preference for mosquito larvae (Lucinda 2003). However, studies on the ecological impacts of these small fishes are lacking, despite consistently being predicted as having high invasion risk (Mendoza et al. 2015; Weyl et al. 2020). Nonetheless, poeciliids in general are capable of outcompeting native species (Mofu et al. 2019a) and have a high predatory impact on invertebrate abundance and diversity (Tsang and Dudgeon 2021), the extent of which varies with environmental context and local abundance (Mofu et al. 2019b). According to the limiting similarity hypothesis, when functionally similar native and invasive species coexist, there is a likelihood of biotic resistance of native fish assemblages where they are not under stress and the habitat is pristine (MacArthur and Levins 1967). However, this may vary depending on the niche plasticity of both the native and invasive species, as well as localized patterns of resource availability which may allow the invader to occupy a previously unexploited niche or broadening its trophic niche under competition (Dominguez et al. 2021). In Maranhão there are five native poeciliid species: *Poecilia (Micro-poecilia) branneri* Eigenmann, 1894, *Poecilia (Micro-poecilia) sarrafae* Bragança & Costa, 2011, *Poecilia (Pamphorichthys) hollandi* (Henn, 1916), *Poecilia (Pamphorichthys) araguaiensis* (Costa, 1991), and *Poecilia (Poecilia) vivipara* Bloch & Schneider, 1801 (Figueiredo 1997; Bragança and Costa 2011; Ramos et al. 2014; Melo et al. 2016; Piorski et al. 2017; Brito et al. 2019, 2020; Guimarães et al. 2020a, 2020b, 2021; Oliveira et al. 2020), as well as diverse yet functionally similar small fish assemblages (Oliveira et al. 2020). Thus, there is a possibility that a successful invasion by *X. maculatus* may present a threat to native species through competition. However, to assess the impact caused by these invasive species in northeastern Brazil, particular ecological conditions should be investigated, such as the abundance of invasive fishes and their distribution and environmental parameters. This is especially important in areas of increased urbanization, which have conditions that facilitate invasions through multiple environmental stressors (Santana et al. 2020; Jackson et al. 2021).

Patterns of increased fish invasions, including those from the aquarium trade, into Neotropical assemblages are attributed to increase in biotic homogenization of megadiverse systems (Tickner et al. 2020; Vitule et al. 2021). Thus, we highlight the first record of the non-native *X. maculatus* in the island of São Luís as a warning for the negative impact of invasive species introductions

in Maranhão, especially on small native species of fishes.

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## Authors' Contributions

Conceptualization: FPO, JS. Data curation: ECG, JPS, PSB. Funding acquisition: FPO. Investigation: PHNB. Supervision: ECG, FPO, JPS. Validation: PHNB. Visualization: ECG, FPO, PHNB. Writing – original draft: FPO. Writing – review and editing: ECG, JPS, PSB, JS, PHNB.

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